Carderock Division
Naval Surface Warfare Center
Philadelphia, PA 19112-1403

NSWCCD-62-TR-2002/02 July 2002

Survivability, Structures, and Materials Directorate
Technical Report

Predicting The UV Exposure At Philadelphia, PA

by

Dr. James R. Slusser
Colorado State University
Fort Collins, CO 80523

Predicting The UV Exposure At Philadelphia, PA
NSWCCD-62-TR-2002/02

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 2002	Final Report

4. TITLE AND SUBTITLE
Predicting The UV Exposure At Philadephia, PA

5. FUNDING NUMBERS
N65540-02-M-0099

6. AUTHOR(S)
Dr. James R. Slusser

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USDA UV-B Monitoring and Reseach Program
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center
Carderock Division, Code 624, Bldg 619
1569 Constitution Avenue
Philadelphia, PA 19112-1403

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NSWCCD-62-TR-2002/02

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The Naval Surface Warfare Center has materials exposed for outdoor weathering and exposure at three sites: Philadelphia, PA; Miami, FL; and Wittman, AZ. The Miami, FL and Wittman, AZ test sites are run by Atlas Weathering Service and are instrumented to measure UV-A plus UV-B solar radiation using the Eppley TUVR. Since there is no Eppley TUVR at Philadelphia, PA, an estimate is made of the radiation a TUVR would measure at that site. This estimate is based on establishing the relationship between the accumulated exposure measured by a TUVR at Miami, FL and the 368 nm channel of a USDA UV radiometer located 65 km distance at Everglades National Park, FL. The ratio of accumulated exposures of the USDA 368 nm channel and the TUVR is constant to within 5% over the 7 week, 13 week, 25 week, 49 week and 97 week periods. A second USDA UV radiometer located at Beltsvillle, MD was in operation during these periods about 185 km from the NAVY test site in Philadelphia, PA. Using the accumulated exposures of the USDA 368 nm channel at Beltsville, MD along with the ratios of the USDA 368 nm channel and the Atlas TUVR developed from the FL data, an estimate is made of the radiation a TUVR in Philadelphia, PA, would measure over the 5 test periods. Sources of error are discussed and recommendations made.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	10
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

UNCLASSIFIED

PREDICTING THE UV EXPOSURE AT PHILADELPHIA, PA

US NAVY CONTRACT N65540-02-M-0099

PERFORMED BY

Dr. James R. Slusser
Research Scientist
Director, USDA UV-B Monitoring and Research Program
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523
sluss@uvb.nrel.colostate.edu

April 29, 2002

CONTENTS

TABLES

FIGURES

ABSTRACT

The Naval Surface Warfare Center has materials exposed for outdoor weathering and exposure at three sites: Philadelphia, PA; Miami, FL; and Wittman, AZ. The Miami, FL and Wittman, AZ test sites are run by Atlas Weathering Service and are instrumented to measure UV-A plus UV-B solar radiation using the Eppley TUVR. Since there is no Eppley TUVR at Philadelphia, PA, an estimate is made of the radiation a TUVR would measure at that site. This estimate is based on establishing the relationship between the accumulated exposure measured by a TUVR at Miami, FL and the 368 nm channel of a USDA UV radiometer located 65 km distance at Everglades National Park, FL. The ratio of accumulated exposures of the USDA 368 nm channel and the TUVR is constant to within 5% over the 7 week, 13 week, 25 week, 49 week and 97 week periods. A second USDA UV radiometer located at Beltsvillle, MD was in operation during these periods about 185 km from the NAVY test site in Philadelphia, PA. Using the accumulated exposures of the USDA 368 nm channel at Beltsville, MD along with the ratios of the USDA 368 nm channel and the Atlas TUVR developed from the FL data, an estimate is made of the radiation a TUVR in Philadelphia, PA, would measure over the 5 test periods. Sources of error are discussed and recommendations made.

INTRODUCTION

Ultraviolet radiation from the Sun reaching the Earth's surface is a major cause of degradation of coatings, paints, plastics, and fabrics which receive outdoor exposure[1]. Ultraviolet radiation is composed of UV-A (320 to 400 nm) and the more damaging UV-B (280 to 320 nm). Radiation from the Sun can pass thru the atmosphere, be scattered (change direction), or be absorbed. In the UV-B region, ozone is the main absorber and is responsible for the sharp cutoff of radiation with wavelengths < 290 nm. Clouds, air molecules, and aerosols scatter in both UV-A and UV-B regions.

METHODS

The Naval Surface Warfare Center has materials exposed for outdoor weathering at three sites: Philadelphia, PA; Miami, FL; and Wittman, AZ. The Miami, FL and Wittman, AZ test sites are run by Atlas Weathering Service and are instrumented to measure UV-A plus UV-B solar radiation using the Eppley TUVR tilted 5° from the level horizontal. The effect of this tilt is negligible. Since there is no

Eppley TUVR at Philadelphia, PA, an estimate is made of the radiation a TUVR would measure at that site. Figure 1 shows the relative spectral response of the TUVR[2] which measures UV-A plus UV-B. The USDA UV-B Monitoring and Research Program[3] measures total horizontal (no tilt) UV radiation at 28 US, 2 Canadian and 1 New Zealand sites (http://UV-B.nrel.colostate.edu). Figure 2 shows the relative spectral response of the 368 nm channel of a USDA UV radiometer calibrated at the NOAA Central UV Calibration Facility[4] which measures a narrow portion (2 nm) of the UV-A. Because the spectral response of the two instruments are different and because the spectral distribution of UV changes with solar zenith angle (SZA, the angle the Sun makes with the vertical) and column ozone amount, correction factors are required [5] to correlate the two measurements. Correction factors for different SZAs and column ozone amounts to account for the different spectral response of the TUVR and the USDA 368 nm channel were generated using a radiative transfer model[6] and are shown in Figure 3. Column ozone, which varies irregularly between 250 Dobson units (DU) and 400 DU, has a negligible effect and may be safely ignored. The ratio of USDA 368 nm channel to the TUVR should be multiplied by these factors. For SZAs less than 50°, the correction factors are between 1.0 and 1.05.

The SZA is the primary driver governing the amount of UV reaching the Earth. The SZA varies with latitude, season, and time of day. Figure 4 shows the noon values of SZA throughout the year at Miami and Everglades National Park. Figure 5 shows the same for Philadelphia and Beltsville. All things being equal (cloud, column ozone, aerosol amount; and elevation), Miami and Everglades, which are further south and always have smaller SZAs, will always receive much more UV-A plus UV-B than Philadelphia and Beltsville. It can be seen that in the course of one year the noon SZAs at Miami and Everglades vary between about 3° and 50°, while the noon SZAs at Philadelphia and Beltsville vary between about 16° and 63°. For all four sites the noon SZAs are less than 55° from day number 50 until day number 300. During these 250 days the Sun is at its highest and radiant exposure is far greater than the 116 days when the winter noon SZAs at Philadelphia and Beltsville are greater than 55°. Referring to Figure 3, one sees that for all four sites the correction factors are between 1.0 and 1.08 (SZA < 55°) from 50 until day number 300. Therefore, the correction factors may be ignored and will be included in the uncertainty analysis below.

The estimate of UV-A plus UV-B at Philadelphia is based on establishing the relationship between the accumulated exposure measured by a TUVR at Miami, FL and the 368 nm channel of a USDA UV radiometer located 65 km distance at Everglades National Park, FL. The ratio of accumulated exposures of the USDA 368 nm channel and the TUVR was constant to within 5% over the 7 week, 13 week, 25 week, 49 week, and 97 week periods. A second USDA UV radiometer located at Beltsville, MD was in operation during this period about 185 km south from the NAVY test site in Philadelphia, PA. Table 1 shows the latitude, longitude, and ground level elevation of the four sites. Elevation differences of less than 500 m are not important in such comparisons.

RESULTS

Using the accumulated exposures of the USDA 368 nm at Beltsville, MD, along with the ratios of the USDA 368 nm channel to the Atlas TUVR developed from the FL data (Table 2), an estimate was made of the radiation a TUVR in Philadelphia, PA, would measure over the 7 week, 13 week, 25 week, 49 week, and 97 week test periods. The predicted UV-A plus UV-B that a TUVR would measure at Philadelphia are presented in Table 3. Sources of error are as follows. The radiometric stability of the Eppley TUVR and the USDA 368 nm channel radiometers[7] are estimated to vary less than ± 5% over the 97 week period based on annual calibrations. It is estimated that the uncertainty of the ratio due to the distance between nearby paired sites (Miami and Everglades, FL; Beltsville, MD and Philadelphia, PA) is about 5%. The neglect of the correction factors to the ratio due to the different latitudes between the two FL sites and the more northerly Philadelphia and Beltsville site introduces about another 5%. Finally by combining these random and independent errors using the root mean square technique[8], the overall uncertainty of the estimate of the UV-A plus UV-B accumulated exposure that an Eppley TUVR would measure at the Philadelphia test site is around ± 9% .

CONCLUSIONS

An estimate of the UV-A plus UV-B accumulated exposure that an Eppley TUVR would measure at Philadelphia over the 7 week, 13 week, 25 week, 49 week, and 97 week periods has been made. This estimate was performed on the basis of the sound correlation demonstrated between the accumulated exposure measured by an Eppley TUVR in Miam, FL and the 368 nm channel of a USDA radiometer at nearby Everglades National Park. This correlation between the TUVR and the USDA 368 channel is expected to hold within ± 9% for closely spaced sites with identical TUVR and USDA 368 nm channel radiometers. It is the author's recommendation that an Eppley TUVR be placed at the Philadelphia test site which will both allow verification of the estimate of UV-A plus UV-B accumulated exposure obtained in this study as well as to make more accurate measurements in the future.

REFERENCES

1. Slusser, J.R., Kinmonth, R. and Leber, R., The Atlas Model LM-3A: A Narrow Band Filter Radiometer for Monitoring Solar Ultraviolet Irradiances and Radiant Exposure, *Atlas Sunspots,* **18**, Chicago, IL., 1988.

2 Thomas Kirk, Eppley Labs, telephone communication, April 2002.

3. Bigelow, D.S., Slusser, J.R., Beaubien, A.F. and Gibson, J.H., The USDA Ultraviolet Radiation Monitoring Program, *Bull. Amer. Meteor. Soc.*, **79**, 601-615, 1998.

4. Slusser, J.R., Gibson, J.H., Kolinski, D., Disterhoft, P., Lantz, K. and Beaubien, A.F., Langley Method of Calibrating UV Filter Radiometers, *J. Geophys. Res.*, **105**, 4841-4849, 2000.

5. Lantz, K.O., Disterhoft, P., DeLuisi, J.J., Early, E., Thompson, A., Bigelow, D. and Slusser, J.R., Methodology for Deriving Erythemal Calibration Factors for UV Broadband Radiometers of the U.S. Central Calibration Facility, *J. Atmos. Ocean. Tech.*, **16**, 1736-1752, 1999.

6. Stamnes, K., Tsay, S.C., Wiscombe W. and Jayaweera, K., Numerically Stable Algorithm for Discrete-ordinate-method Radiative Transfer in Multiple Scattering and Emitting Layered Media, *Appl. Opt., 27,* 2502-2509, 1988.

7. Bigelow, D.S. and Slusser, J.R., Establishing the Stability of Multi-filter UV Rotating Shadow band Radiometers, *J. Geophys. Res.*, **105**, 4833-4830, 2000.

8. Barlow, R. J., *Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences*, 204 pp., John Wiley & Sons, New York, NY, 1989.

Table 1. Coordinates of four sites

Site	Latitude	Longitude	Elevation (m)
Miami, FL	25.77°	80.19°	3
Everglades NP, FL	25.38°	80.68°	0
Beltsville, MD	39.02°	76.95°	34
Philadelphia, PA	39.95°	75.16°	12

Table 2. Exposure data for Everglades National Park, FL (USDA, units of KJoules m^{-2} nm^{-1}) and Miami, FL (Atlas, units of KJoules m^{-2}).

Summary Period (YYMMDD)	USDA 368 nm	Atlas TUVR 5°	Ratio 368 nm / TUVR
7 Weeks (000501 - 000619)	968	49	19.76
13 Weeks (000501 - 000731)	1694	87	19.47
25 Weeks (000501 - 001023)	3010	154	19.55
49 Weeks (000501 - 010409)	5441	272	20.00
97 Weeks (000501 - 020311)	10383	510	20.36

Table 3: Exposure data for Beltsville, MD (USDA units of KJoules m^{-2} nm^{-1}) extrapolated to simulate a TUVR at Philadelphia, PA (units of MJoules m^{-2})

Summary Period	USDA 368 nm	Extrapolated to Philadelphia, PA TUVR 5°
7 Weeks (000501 - 000619)	712	36.0
13 Weeks (000501 - 000731)	1345	69.1
25 Weeks (000501 - 001023)	2267	116.0
49 Weeks (000501 - 010409)	3407	170.3
97 Weeks (000501 - 020311)	7645	375.5

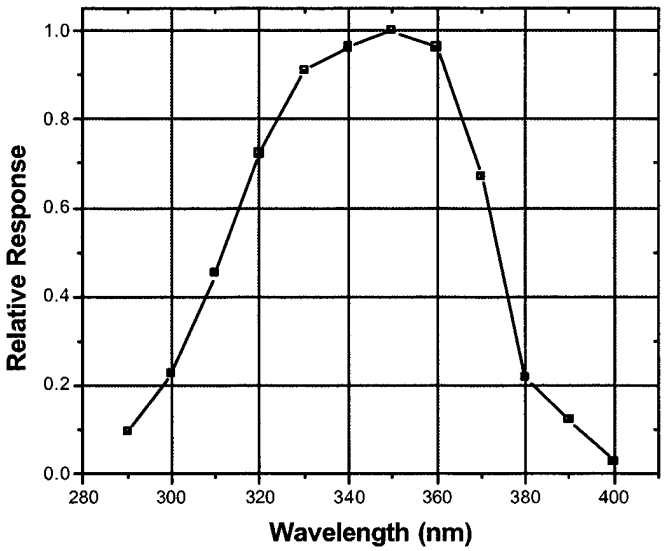

Figure 1: Relative spectral response of the Eppley TUVR used at Atlas Weathering site in Miami, FL.

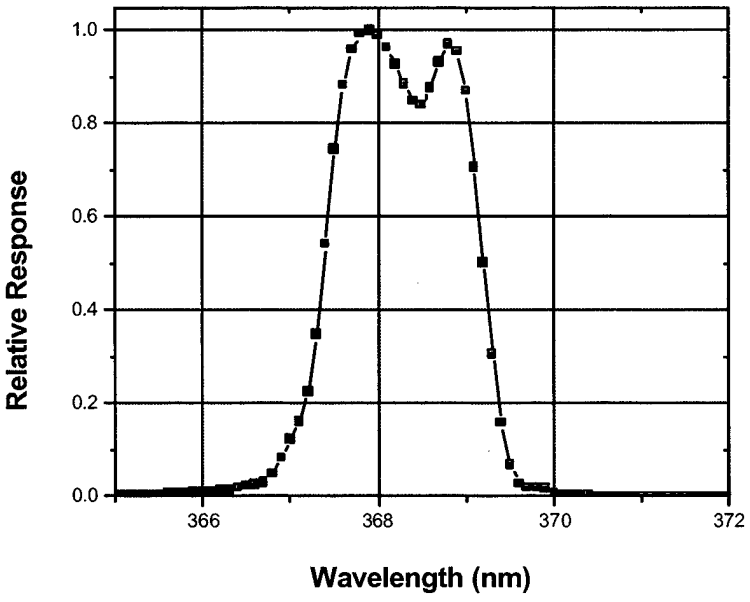

Figure 2:: Relative spectral response of USDA Yankee 368 nm channel at Everglades, FL.

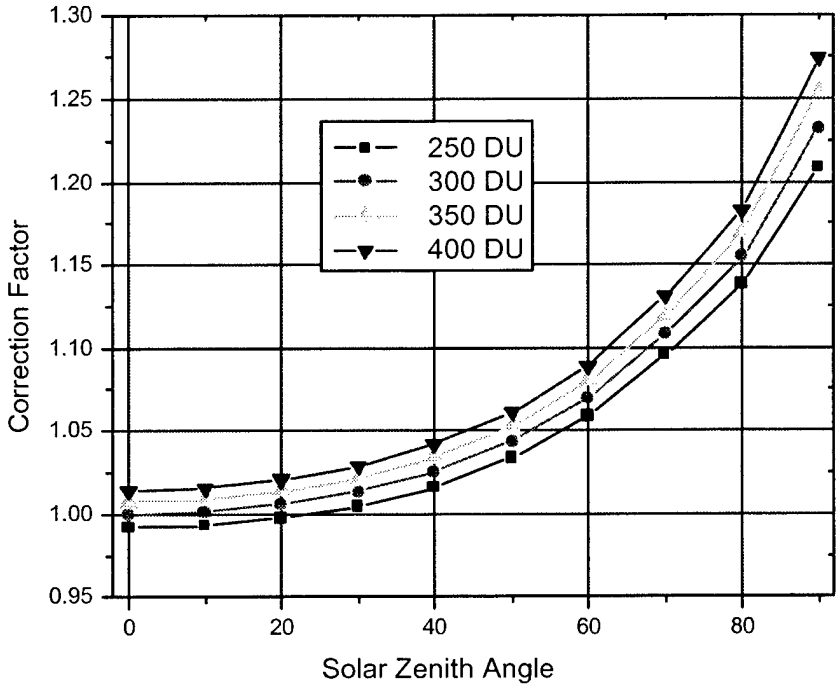

Figure 3: Correction factors for different solar zenith angles (SZAs) and column ozone amounts in Dobson units (DU) by which the ratio of USDA 368 nm channel / TUVR must be multiplied. For SZAs < 50°, correction factors are less than 1.05.

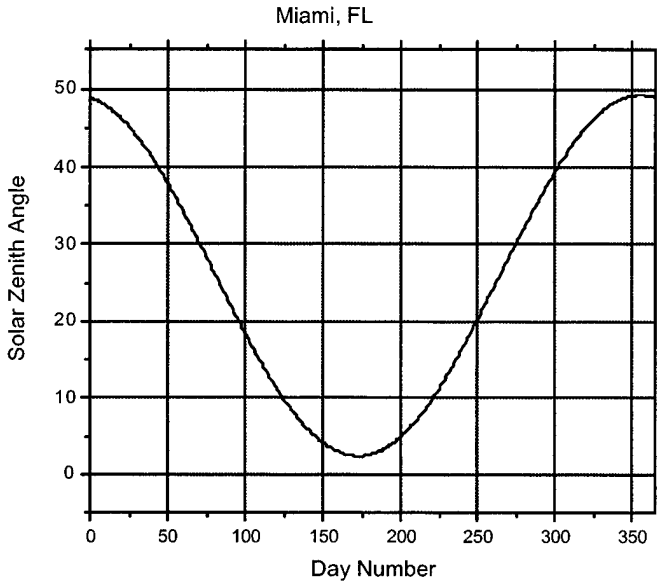

Figure 4: Seasonal variation in noon solar zenith angle at Miami and Everglades, FL.

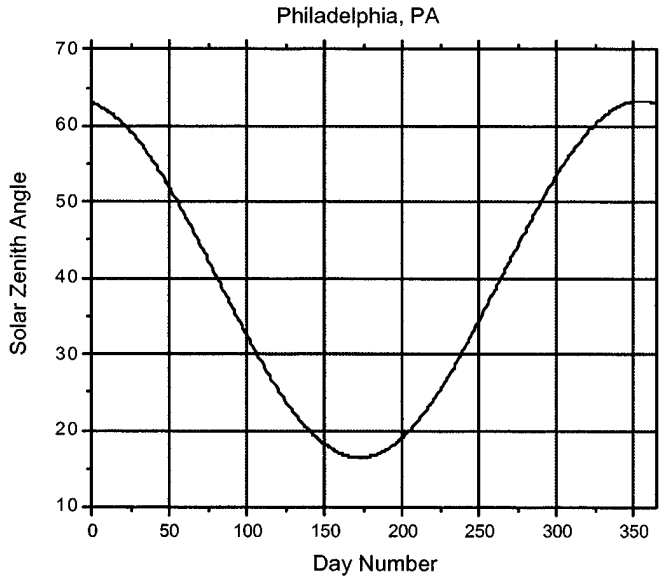

Figure 5: Seasonal variation in solar zenith angle at Philadelphia, PA and Beltsville, MD.

DISTRIBUTION LIST

NSWCCD DISTRIBUTION

Copies	
2	Commander, Carderock Division Naval Surface Warfare Center 9500 MacArthur Blvd. West Bethesda, MD 20817-5700
1	60 (Beach)
1	603 (Hardy)

Copies	
4	Commanding Officer Carderock Division Naval Surface Warfare Center Naval Business Center Philadelphia, PA 19112-5083
1	62 (Eichinger)
1	624 (Steck/File)
2	624 (Eng)

ARL DISTRIBUTION

Copies	
2	Commander Army Research Laboratory AMSRL-WM-MA Bldg 4600, Deer Creek Loop Attn: W. Kosik Aberdeen Proving Ground, MD 21005-5069

NAWCAD DISTRIBUTION

Copies	
2	Commander Naval Air Warfare Center, Aircraft Division Code 4341, Bldg 2188 48066 Shaw Road Unit 5 Attn: K.J. Kovaleski Patuxent River, MD 20670-1908

DTIC DISTRIBUTION

Copies	
2	Defense Technical Information Center 8725 John J. Klingman Road, Suite 0944 Attn: DTIC-O Fort Belvoir, VA 22060-6218

SERDP DISTRIBUTION

Copies	
2	SERDP Program Office 901 North Stuart Street, Suite 303 Attn: C. Pellerin Arlington, VA 22203

CO State University DISTRIBUTION

Copies	
2	CO State University Natural Resource Ecology Laboratory Attn: J.R. Slussser Fort Collins, CO 80523